AIL Report Number 1400-6

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FINAL REPORT

Contract FAA/BRD-403

STATISTICAL ANALYSIS OF AIRCRAFT DELAY

JULY 1965

Prepared for

FEDERAL AVIATION AGENCY
Office of Policy Development

by

AIRBORNE INSTRUMENTS LABORATORY
A Division of Cutler-Hammer, Inc.
Deer Park, Long Island, New York

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March 1965

Prepared by

I. S. Wisepart and M. A. Warskow

This report has been prepared by Airborne Instruments Laboratory for the Office of Policy Development, Federal Aviation Agency, under Contract FAA/BRD-403. The contents of this report reflect the views of the contractor, who is responsible for the facts and the accuracy of the data presented herein, and do not necessarily reflect the official views or policy of the FAA. This report does not constitute a standard, specification or regulation.

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SUMMARY

The purpose of this work is to analyze the delay to samples of various segments of the aircraft population (air carrier, general aviation, military, and one airline) and to determine the extent to which the amounts of delay are typical of the average delay of the total traffic. Information obtained in previous AIL work for the FAA and others was used as the basis for this study. The data were selected from days during the years from 1961 to 1964; the delays to aircraft operating during the busiest hours of those days were analyzed. Aircraft that experienced no delays during these hours were included in the sample. Sample sizes for each case analyzed were as high as 361. There was a total of 33 cases in addition to three composites. The total number of samples was 5054.

A computer performed the statistical analysis of the data from six major airports in the United States. For each of the total-traffic samples, 95-percent confidence intervals were computed and the average delays of each segment were tested to determine whether they were within the confidence intervals.

Based on the six airports studied, it is generally believed that at the major air-carrier airports air-carrier delay is a good representative of total-traffic delay. However, the delays experienced by general aviation and a single airline (United Airlines was selected) were found to be significantly different from the total-traffic delays. It was also found that United Airlines delays for the cases studied were not typical of total air-carrier delays.

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I. INTRODUCTION

Aircraft arriving at or departing from an airport experience delays resulting from their random demand for service (reference 1). Even at low movement rates, there is some delay and, as the movement rate increases, the average delay increases but not proportionately with the movement rate. AIL has found that for high movement rates a small increase in the number of movements results in a disproportionately large increase in average delay (references 1 and 2). Figure 1 shows a curve for VFR departures.

Delay is a function of the spacing between aircraft--that is, between arrivals, between departures, or between departures and arrivals. Spacing depends on factors such as:

1. Runway layout (exits, taxiways, crossings, etc.),
2. Aircraft population,
3. Ratio of arrivals to departures,
4. Weather,
5. Operating practices of company.

Aircraft population is determined on the basis of the runway performance of aircraft during takeoff and landing. Aircraft types are divided into the following distinct classes:

Class A — All jet aircraft normally requiring runway lengths exceeding 6000 feet (corrected to sea level) for takeoff and/or landing.

Class B (a) — Piston and turboprop aircraft having a normal loaded weight exceeding 36,000 pounds.

(b) — Jet aircraft not included in Class A but having a normal loaded weight exceeding 25,000 pounds.

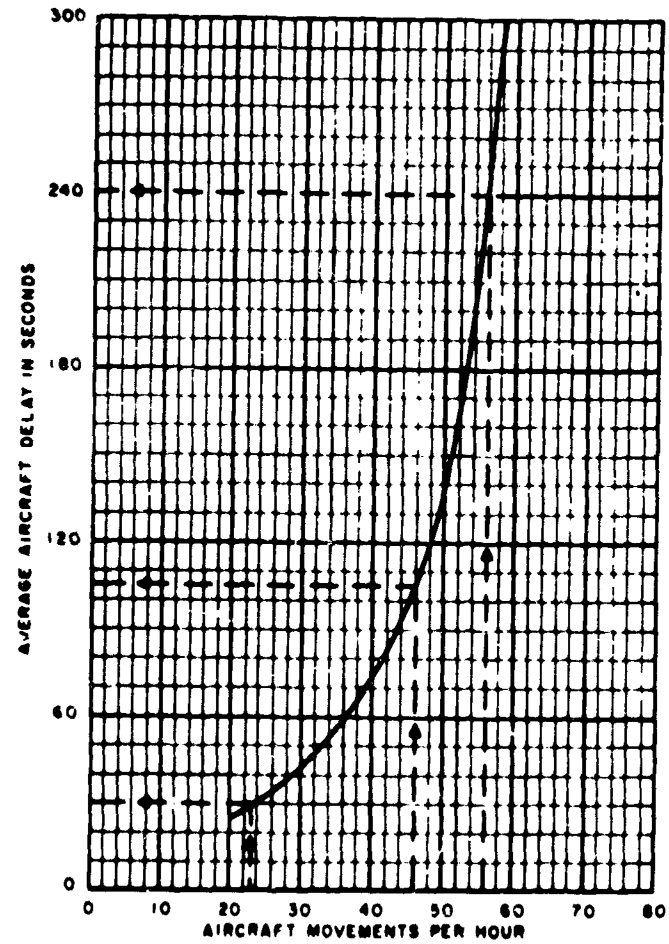

FIGURE 1. AVERAGE AIRCRAFT DELAY VS MOVEMENT RATE

Class C (a)	Piston and turboprop aircraft having a normal loaded weight greater than 8000 pounds and less than 36, 000 pounds.
(b)	Jet aircraft having a normal loaded weight greater than 8000 pounds but less than 25, 000 pounds.
Class D	All light twin-engine piston and turboprop aircraft having a normal loaded weight less than 8000 pounds and some high-performance single-engine light aircraft (such as the Beech Bonanza).
Class E	All single-engine light aircraft other than those included in Class D.

Since the determination of aircraft delay is important in assessing the quality of service provided by an airport, any technique used as a basis for making generalized conclusions must be based on data representative of the entire population of aircraft. The purpose of this work is to analyze the delay to samples of various segments of the aircraft population (air carrier, general aviation, military, and United Airlines as a typical airline that operated at all of the airports studied) and to determine the extent to which the amounts of delay are typical of the average delay of the total traffic. Various samples of the population must be selected and the extent to which each is representative must be determined. This can be accomplished by proven statistical methods.

II. METHOD OF ANALYSIS

A. DELAY DATA

Information obtained and reduced in previous AIL work was used as the basis for this study. Such information was gathered from the following sources:

1. Tower surveys,
2. Photographing the Airport Surveillance Radar (ASR) scope,
3. Photographing the Airport Surface Detection Equipment (ASDE),
4. Recording controller/pilot communications on magnetic tape,
5. Tower and center strips.

In general, tower surveys consist of making pencil and magnetic tape recordings of:

1. Weather,
2. Runway,
3. Arrival or departure,
4. Equipment type and/or class,
5. Name of operator (air carrier, general aviation, military, etc.),

For departures:

6. Time that the aircraft enters the queue,
7. Ready-to-go-times,
8. Time that the aircraft moves toward the active runway,
9. Time that the aircraft enters the active runway,
10. Time that the aircraft starts to roll,
11. Number of aircraft in the queue.

For arrivals:

12. Time that the aircraft passes over the threshold,

13. Time that the aircraft exits from the active runway,

14. Name of exit taxiway.

Tower and center strips and tape recordings of communications yield information such as aircraft identification and aircraft flight plans and reroutings. ASR photographs provide information on aircraft holding and routing. ASDE photographs assist in obtaining departure delay, taxiing patterns, and runway crossing delays.

All of these techniques have been used to obtain delays to aircraft. In this study, departure delay is defined as the time from when the pilot calls "Ready to Go" to when the aircraft starts to roll. Thus, runup and instrument-check times are excluded from the delay. In a few cases, ready-to-go times were not available but the enter-queue to start-roll times were. Therefore, to estimate the ready-to-go times, it was necessary to perform a survey at Newark Airport during a VFR day, which would substantiate earlier data regarding the enter-queue to ready-to-go times. The average runup times in Table I were subtracted from the enter-queue to start-roll times. These times also include a few seconds for an undelayed aircraft to take position on the active runway. Runup times are best obtained during VFR weather and when queue sizes are small. This reduces the possibility of obtaining artifically long runup times when the pilot realizes that he will not immediately be given takeoff clearance because of wider separations or other aircraft ahead of him.

Arrival delays include delays during rerouting and holding in stacks.

TABLE I
AIRCRAFT RUNUP TIMES

Class	Runup Times in Seconds		
	Washington National Airport 29 March 1961	Newark Airport 5 February 1965	Rounded Weighted Averages
A		44 (19)	40
B^{T*}	72 (56)**	46 (16)	60
B	138 (125)	142 (42)	140
C	128 (41)	68 (11)	120
D	91 (37)	82 (19)	90
E	90 (31)	48 (9)	90

* Turboprop aircraft.

** Numbers in parentheses are the number of aircraft in the sample.

Six airports were studied under the conditions listed in Table II. At each airport, only continuous periods with the same or similar runway combinations were included as individual cases. If the runway combination changed to one that resulted in a different operating capacity, * the data were separated to form a new case.

Aircraft experiencing no delay during these hours were included in the sample.

In VFR weather conditions, only departure delay was considered because arrival delay was found to be negligible in the

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* This occurred at John F. Kennedy International Airport on 18 January 1963. At 1640, the departure runway was changed from 13R/L to 31L but the arrival runway remained 4R.

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TABLE II
SUMMARY OF SCOPE OF DELAY ANALYSIS

Departure Delay (D) or Arrival Delay (A)	Case	Airport	Date	Time	Departure Runway(s)	Arrival Runway(s)	VFR(V) or IFR(I)	SAMPLE SIZE Air Carrier	United Airlines	General Aviation	Military	Total Traffic
D	1	JFK	12-14-62	1300-1720	31L/R	31L/R	V	75	9	27	0	102
	2	JFK	12-18-62	1319-1657	31L/R	4R(31R)	I	61	10	5	2	69
	3	JFK	12-19-62	1316-1659	25(31R)	22L(22R)	I	64	8	11	2	77
	4	JFK	1-11-63	1337-1700	31L	4R	I	64	8	3	1	69
	5	JFK	1-18-63	1300-1638	13R/L	4R	I	65	9	5	0	70
	6	JFK	1-18-63	1645-1726	31L	4R	I	12	2	2	1	15
	7	JFK	2-12-63	1338-1744	31L	4R	I	68	12	1	1	70
	8	JFK	9-13-63	1400-2000	31L(31R)	4R (4L)(31R)	V	148	17	27	3	173
	9	JFK	9-25-64	1453-1800	31L(R)	31R(L)	V	55	8	16	0	71
	10	LGA	9-13-63	1315-1800	4(31)	4(31)	V	51	0	83	0	134
	11	DCA	3-29-61	0820-1810	3/33/36	36 33 3	V	184	7	94	10	289
	12	DCA	3-31-61	0845-1845	3/36/33	36 3 33	I	169	6	49	5	225
	13	EWR	9-13-63	1400-2000	4/29	4(29)	V	84	10	44	3	131
	14	ORD	10-19-62	1500-1800	14LR 32RL	14R/22 9/27	V	92	32	19	1	112
	15	ORD	3-7-63	1200-1359	32LR	32 4R/27	I	237	70	23	6	267
	16	ORD	3-8-63	1200-2000	32L/22 27	32R/L/27 22	I	274	85	38	5	317
	17	ORD	4-18-63	1200-1936	9/14R/L 4/22	14L/R	I	241	82	50	6	297
	18	ORD	4-19-63	1200-2000	14R/22 27/32L/R	14R/22 27	V	257	82	52	12	322
	19	ORD	5-16-63	1200-2000	9(14L/4)	14L/R	V	282	89	64	5	351
	20	ORD	5-17-63	1200-2100	32L/R/9 14R(L)	32L/14L/R	V	289	92	58	14	361
	21	ORD	1[illegible]-9-64	1700-1900	32L/R/27 36	32R/L/27	V	85	33	12	2	99
	22	LAX	4-26-61	0900-1722	24L(R)	25R L	V	110	32	32	29	171
	23	LAX	4-27-61	0800-1700	25L(R)	25R/L	I	103	30	53	18	174
	24	LAX	5-3-61	0800-1300	25L/R	25R/L	I	59	21	18	11	88
	25	LAX	5-4-61	0835-1200	25L/R	25L/R	I	48	15	13	10	71
A	26	JFK	12-18-62	1319-1657	31L/R	4R(31R)	I	71	6	13	3	87
	27	JFK	12-19-62	1316-1659	25(31R)	22L(22R)	I	87	6	25	3	118
	28	JFK	1-11-63	1337-1700	31L	4R	I	85	6	6	0	92
	29	JFK	1-18-63	1300-1638	13R/L	4R	I	69	5	8	1	78
	30	JFK	1-18-63	1645-1726	31L	4R-	I	20	1	1	0	21
	31	JFK	2-12-63	1338-1744	31L	4R	I	74	7	2	0	76
	32	JFK	9-13-63	1400-2000	31L(31R)	4R (4L)(31R)	V	175	12	39	2	218
	[illegible]	DCA	3-31-61	[illegible]	[illegible]	[illegible]	I	[illegible]	7	48	7	239

samples examined. In IFR conditions, arrival and departure delay were analyzed except in cases where radar film was not taken for obtaining holding delay.

In some cases, adding the sample sizes of air-carrier, general-aviation, and military aircraft does not result in the total-traffic sample size. This is because FAA-operated aircraft were included in the total-traffic sample but not in any of the other three categories.

B. STATISTICAL BACKGROUND

In Table II, the last five columns list the sample size (n) or the number of operations included within the time period studied. The delays (x_i) of each aircraft operation in the sample space are values of a random variable. The mean (or average) of the sample is

$$\bar{x} = \frac{1}{n} \sum_{i=1}^{n} x_i$$

The sample standard deviation, which is a measure of the spread (or variability) of the individual delays (x_i), is

$$s = \sqrt{\frac{1}{n-1} \sum_{i=1}^{n} (x_i - \bar{x})^2}$$

The delay within $\pm s$ of the sample mean represent 68 percent of the individual delay samples. Note that the larger the sample size (n), the smaller the effect of the -1 on the sample standard deviation. Therefore, the larger the sample size, the closer the sample standard deviation comes to approximating the population standard devia-

tion, which involves division by n rather than n - 1. By population, we mean all the individual delays that the sample is supposed to represent.

Since the purpose of a survey is to obtain a clue to the nature of the population, it is desirable to determine the true mean of the population. This is only possible if the population is finite and all the delays are known. Since neither is true, we must settle for the interval within which the true means will lie. This interval is called the confidence interval because it can only be estimated with a specified "degree of confidence" (reference 3). For example, a 95-percent confidence interval is one that contains the true mean 95 percent of the time. Increasing the degree of confidence, increases the width of the interval.

The confidence interval is defined as

$$\bar{x} - z_{\alpha/2}\frac{s}{\sqrt{n}} < \mu < \bar{x} + z_{\alpha/2}\frac{s}{\sqrt{n}}$$

where

$z_{\alpha/2}$ = lower limit such that the integral of the standard normal density from $z_{\alpha/2}$ to ∞ equals $\alpha/2$,

$1 - \alpha$ = degree of confidence (in our example 0.95),

μ = true mean.

For $1 - \alpha = 0.95$, $z_{\alpha/2} = 1.96$ (reference 3). It should be emphasized that when the population does not have a normal distribution (which is our case, since negative values of delay are impossible), this approximation of the confidence interval is only valid for $n \geq 30$. Also, since $z_{\alpha/2}$ is a constant for a given confidence level, the width of the confidence interval varies directly with the sample standard deviation (for a constant sample size) and inversely with the square root of the sample size (for a constant standard deviation). Thus, increasing the standard deviation tends to increase

the width of the confidence interval; increasing the sample size tends to decrease the width of the confidence interval.

To perform these three calculations (sample mean, sample standard deviation, and 95-percent confidence interval of the true mean), a computer program (number 6.0.012) was found in IBM's program library. This program required some changes to adapt it to the particular needs of this work.

III. DISCUSSION OF RESULTS

Table III shows the outputs of the computer analyses. Figures 2 through 9 were drawn to determine whether the sample in question is an adequate representative of the total traffic. Because each of the cases analyzed represents a different situation, it was necessary to normalize them so that fair comparisons could be made. This was done by dividing all factors by the total-traffic average delay for each case. For example, in case 1 (Table III), the limits of the total-traffic confidence interval were (454-105=) 349 and (454+105=) 559 which, when divided by the total-traffic average delay (454 seconds), become 0.77 and 1.23. The average delays of air carrier, United Airlines, general aviation, and military aircraft were also divided by the total-traffic average delay and these values were plotted on Figures 2 through 9 as a function of the total-traffic sample size to determine their relationship to the 95-percent confidence interval of the true mean.

In Figure 2, we note that the air-carrier departure delay fell outside of the total-traffic confidence interval in only two out of the 24 cases. These were for cases 1 and 10 with total-traffic sample sizes of 102 and 134--corresponding to air-carrier sample sizes of 75 and 51. In case 1, the air-carrier average departure delay was 115 seconds higher than the total-traffic average departure delay (454 seconds) and, in case 10, it was 49 seconds lower. The 115-second difference in average departure delay is the largest of all the cases with the next largest difference (case 6) being 70 seconds (8 percent of the 924-second total-traffic average departure delay).

For case 1, the 115-second difference represents a 25-percent air-carrier difference from the total-traffic average

TABLE III

STATISTICAL RESULTS OF DELAY ANALYSIS

Case	Departure Delay (D) or Arrival Delay (A)	TOTAL TRAFFIC n	TOTAL TRAFFIC $\bar{x}$	TOTAL TRAFFIC s*	TOTAL TRAFFIC 95-percent Confidence Interval*	AIR CARRIER n	AIR CARRIER $\bar{x}$	AIR CARRIER s*	AIR CARRIER 95-percent Confidence Interval*	UNITED AIRLINES n	UNITED AIRLINES $\bar{x}$	UNITED AIRLINES s*	UNITED AIRLINES 95-percent Confidence Interval*	GENERAL AVIATION n	GENERAL AVIATION $\bar{x}$	GENERAL AVIATION s*	GENERAL AVIATION 95-percent Confidence Interval*	MILITARY n	MILITARY $\bar{x}$	MILITARY s*	MILITARY 95-percent Confidence Interval*
1	D	102	454	543	105	75	569	587	133	9	696	784	---	27	137	145	---	0	---	---	---
2		69	245	245	58	61	262	254	64	10	195	218	---	5	85	83	---	2	227	105	---
3		77	194	217	48	64	195	223	55	8	148	103	---	11	189	205	---	2	170	105	---
4		69	353	266	63	64	368	267	65	8	229	130	---	3	184	234	---	1	118	0	---
5		70	660	450	105	65	644	457	111	9	516	364	---	5	872	299	---	0	---	---	---
6		15	924	449	---	12	994	436	---	2	790	31	---	2	380	106	---	1	1172	0	---
7		70	177	139	33	68	179	140	33	12	222	108	---	1	74	0	---	1	130	0	---
8		173	321	291	42	148	349	300	48	17	289	299	---	27	219	242	---	3	451	338	---
9		71	178	198	46	55	183	211	56	8	252	272	---	16	163	151	---	0	---	---	---
10		134	184	282	48	51	135	198	54	0	---	---	---	83	214	321	69	0	---	---	---
11		289	125	110	13	184	133	114	16	7	91	83	---	94	111	103	21	10	67	61	---
12		225	184	173	23	169	197	180	27	6	176	116	---	49	140	134	37	5	132	96	---
13		131	178	200	34	84	194	229	49	10	104	43	---	44	148	146	43	3	166	61	---
14		112	98	122	23	92	93	105	21	32	81	75	26	19	120	187	---	1	125	0	---
15		267	113	137	16	237	112	129	16	70	136	116	27	23	118	197	---	6	96	183	---
16		317	114	143	16	274	116	142	17	85	117	142	30	38	95	147	47	5	169	221	---
17		297	121	119	14	241	126	121	15	82	154	128	28	50	95	104	29	6	137	125	---
18		322	178	209	23	257	187	214	26	82	234	238	51	52	107	132	36	12	296	263	---
19		351	115	165	17	282	128	177	21	89	156	189	39	64	56	86	21	5	310	298	---
20		361	229	270	28	289	239	275	32	92	244	231	47	58	182	244	63	14	216	254	---
21		99	447	342	67	85	473	353	75	33	486	348	119	12	313	223	---	2	184	127	---
22		171	132	152	24	110	115	114	21	32	158	114	40	32	137	209	73	29	193	214	---
23		174	105	131	19	103	102	108	21	30	89	92	33	53	75	100	27	18	200	241	---
24		88	100	82	17	59	110	90	23	21	114	85	---	18	83	66	---	11	77	47	---
25		71	106	113	26	48	124	129	36	15	128	153	---	13	61	47	---	10	94	67	---
Composite Depart Delay		4125	185	244	7	3177	198	256	9	769	193	228	16	799	137	193	13	147	185	218	35
26	A	87	13	55	12	71	15	61	14	6	28	69	---	13	0	0	---	3	0	0	---
27		118	37	99	18	87	46	112	24	6	44	108	---	25	2	12	---	3	93	86	---
28		92	76	199	41	85	82	206	44	6	226	313	---	6	16	40	---	0	---	---	---
29		78	159	325	72	69	170	335	79	5	51	115	---	8	86	244	---	1	0	0	---
30		21	939	466	---	20	986	424	---	1	1295	0	---	1	0	0	---	0	---	---	---
31		76	16	63	14	74	13	60	14	7	55	97	---	2	104	147	---	0	---	---	---
32		218	22	91	12	175	28	101	15	12	88	159	---	39	0	0	0	2	0	0	---
33		239	64	197	25	181	75	220	32	7	20	54	---	48	23	76	21	7	84	146	---
Composite [illegible]		929	71	224	14	762	83	243	17	50	98	231	64	142	15	75	12	16	54	107	52
[illegible]posite of Delay		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	195	[illegible]	[illegible]	172	213	33

* $\pm$ is omitted for simplicity.

Note: Units for $\bar{x}$, s, and the confidence interval are seconds.

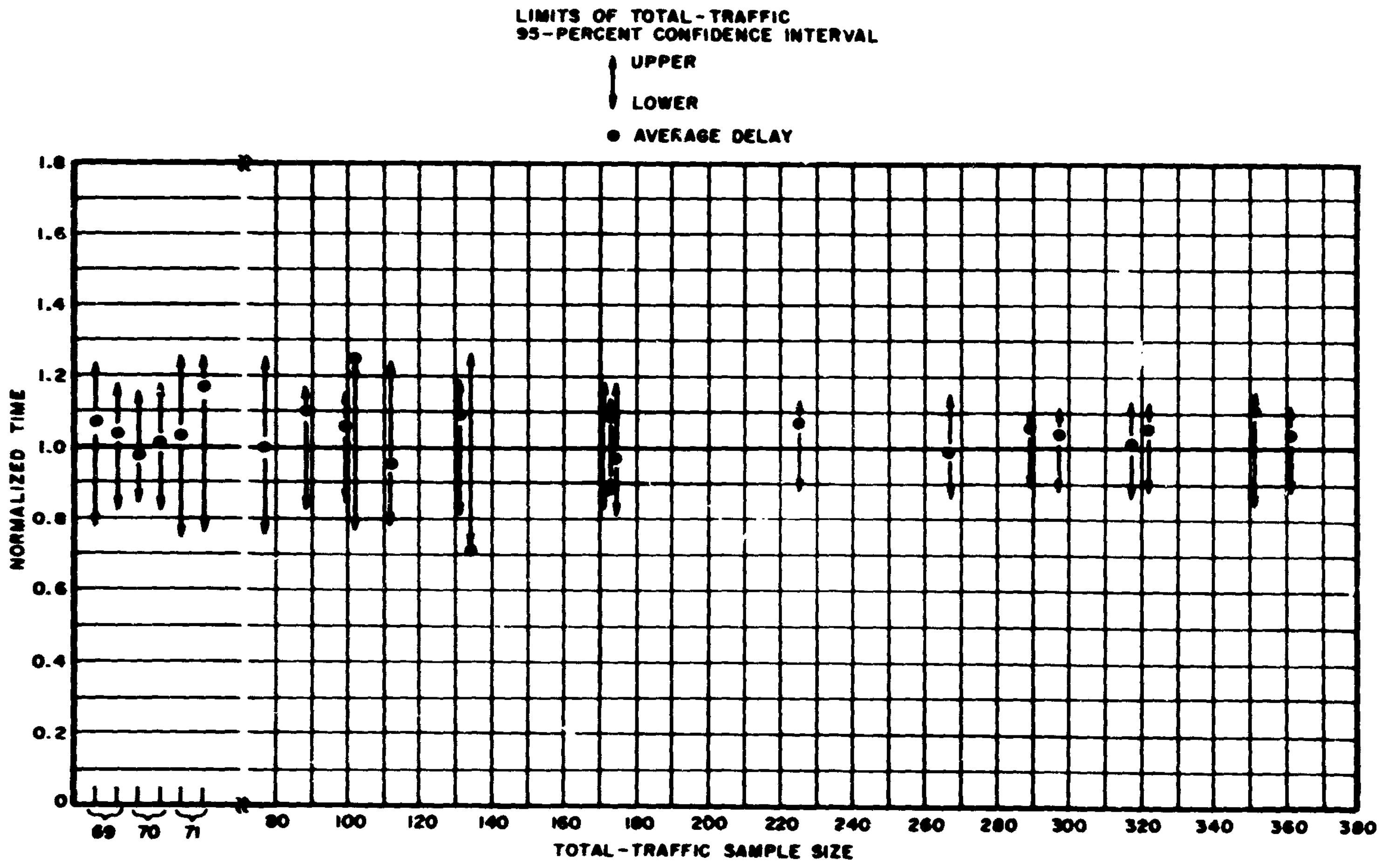

FIGURE 2. RELATIONSHIP OF AIR-CARRIER DEPARTURE DELAY TO 95-PERCENT CONFIDENCE INTERVAL OF TOTAL-TRAFFIC TRUE MEAN

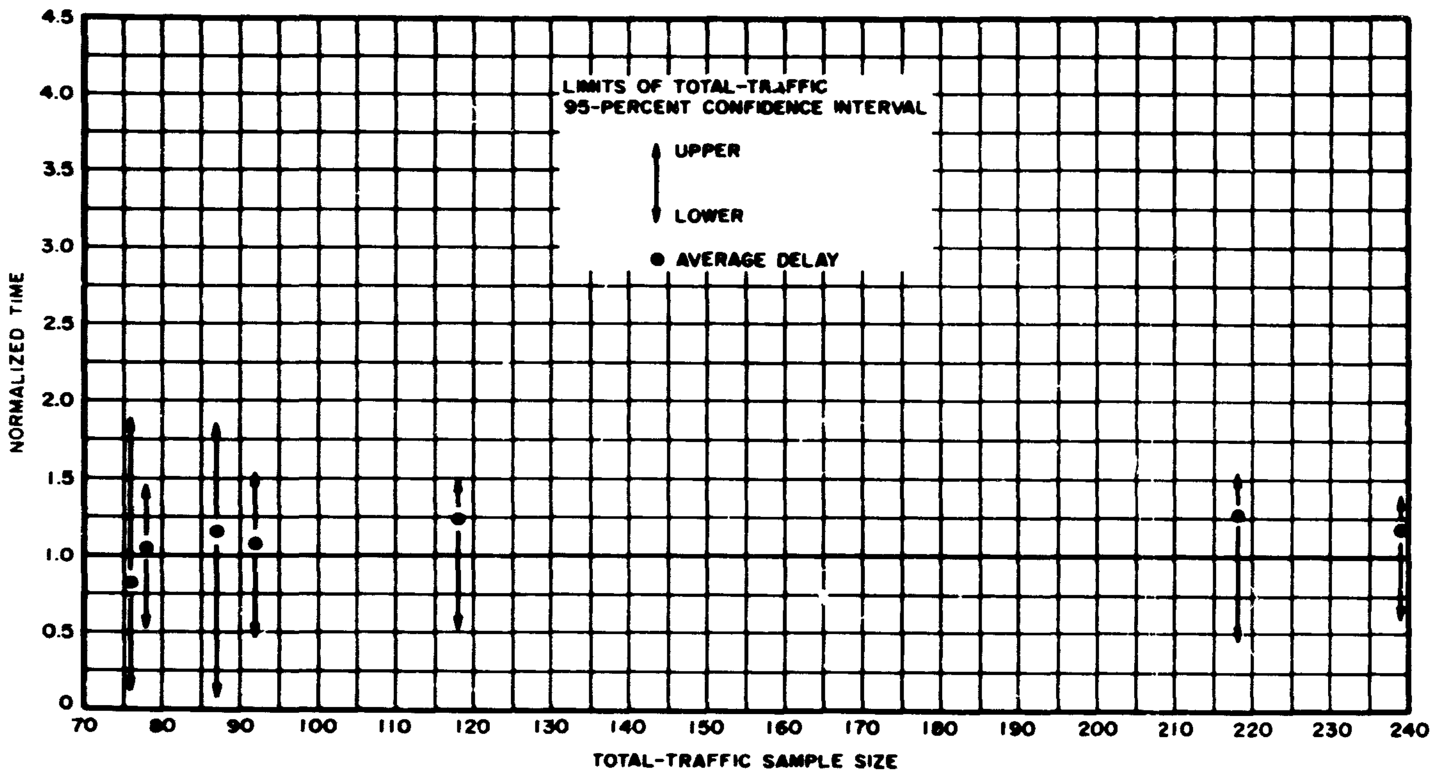

FIGURE 3. RELATIONSHIP OF AIR-CARRIER ARRIVAL DELAY TO 95-PERCENT CONFIDENCE INTERVAL OF TOTAL-TRAFFIC TRUE MEAN

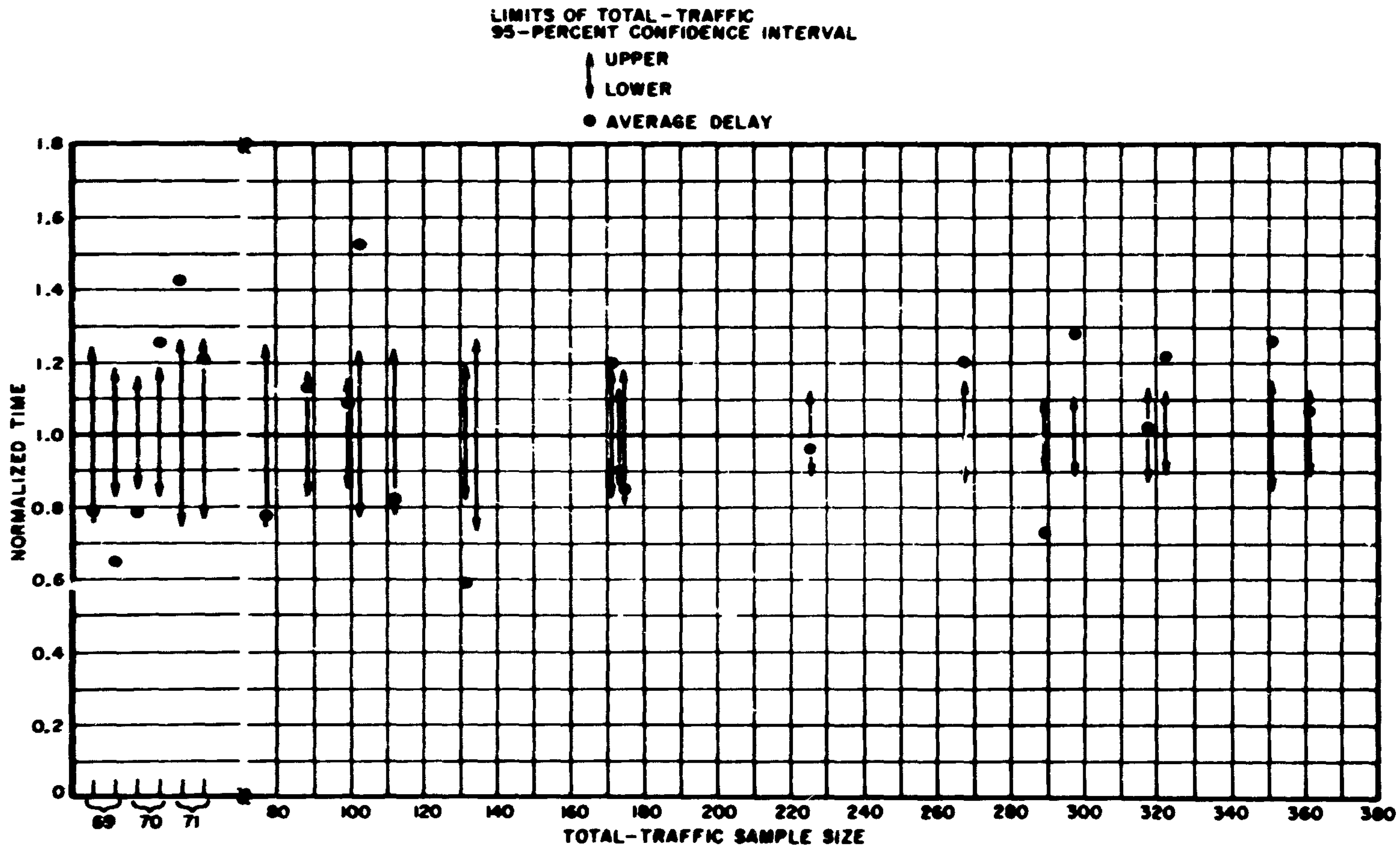

FIGURE 4. RELATIONSHIP OF UNITED AIRLINES DEPARTURE DELAY TO 95-PERCENT CONFIDENCE INTERVAL OF TOTAL-TRAFFIC TRUE MEAN

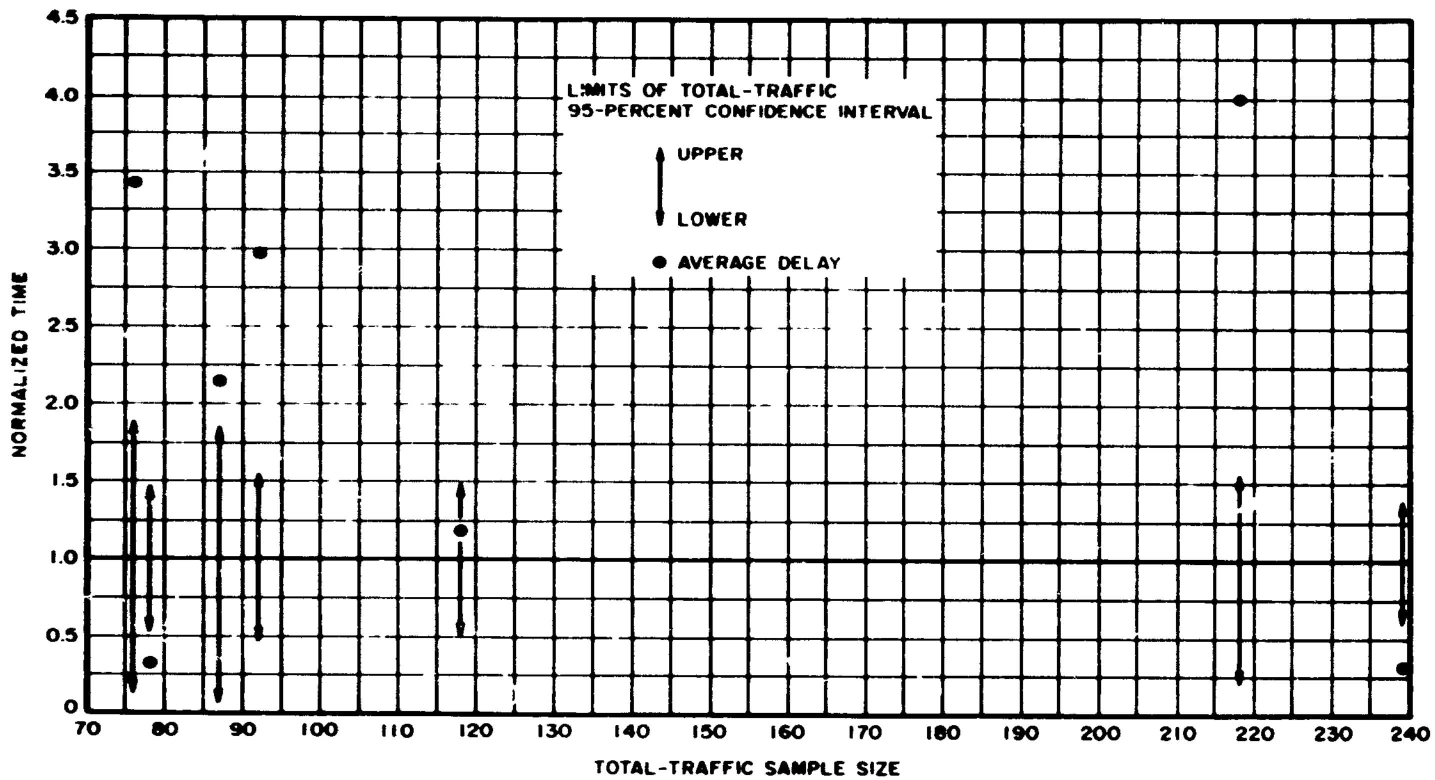

FIGURE 5. RELATIONSHIP OF UNITED AIRLINES ARRIVAL DELAY TO 95-PERCENT CONFIDENCE INTERVAL OF TOTAL-TRAFFIC TRUE MEAN

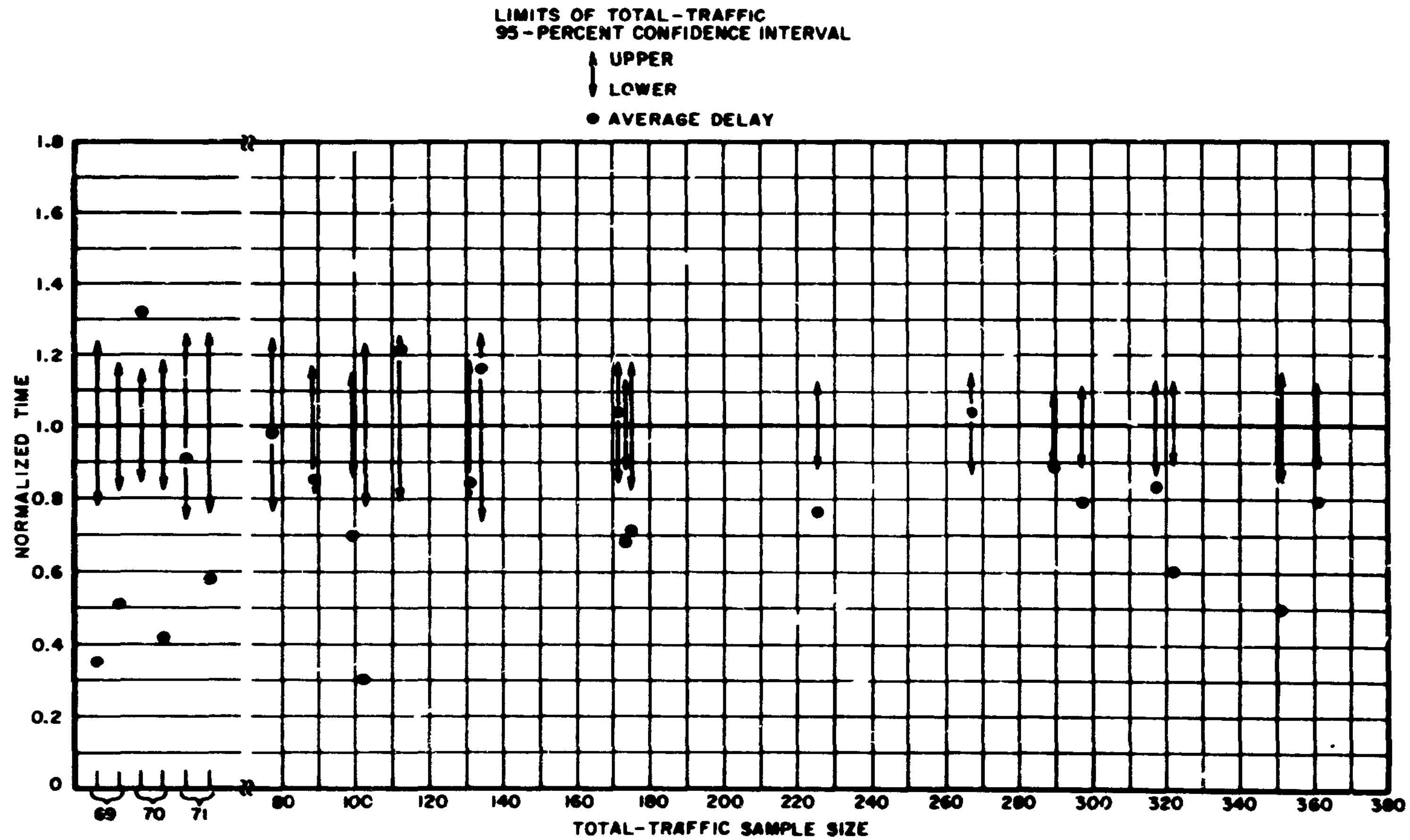

FIGURE 6. RELATIONSHIP OF GENERAL-AVIATION DEPARTURE DELAY TO 95-PERCENT CONFIDENCE INTERVAL OF TOTAL-TRAFFIC TRUE MEAN

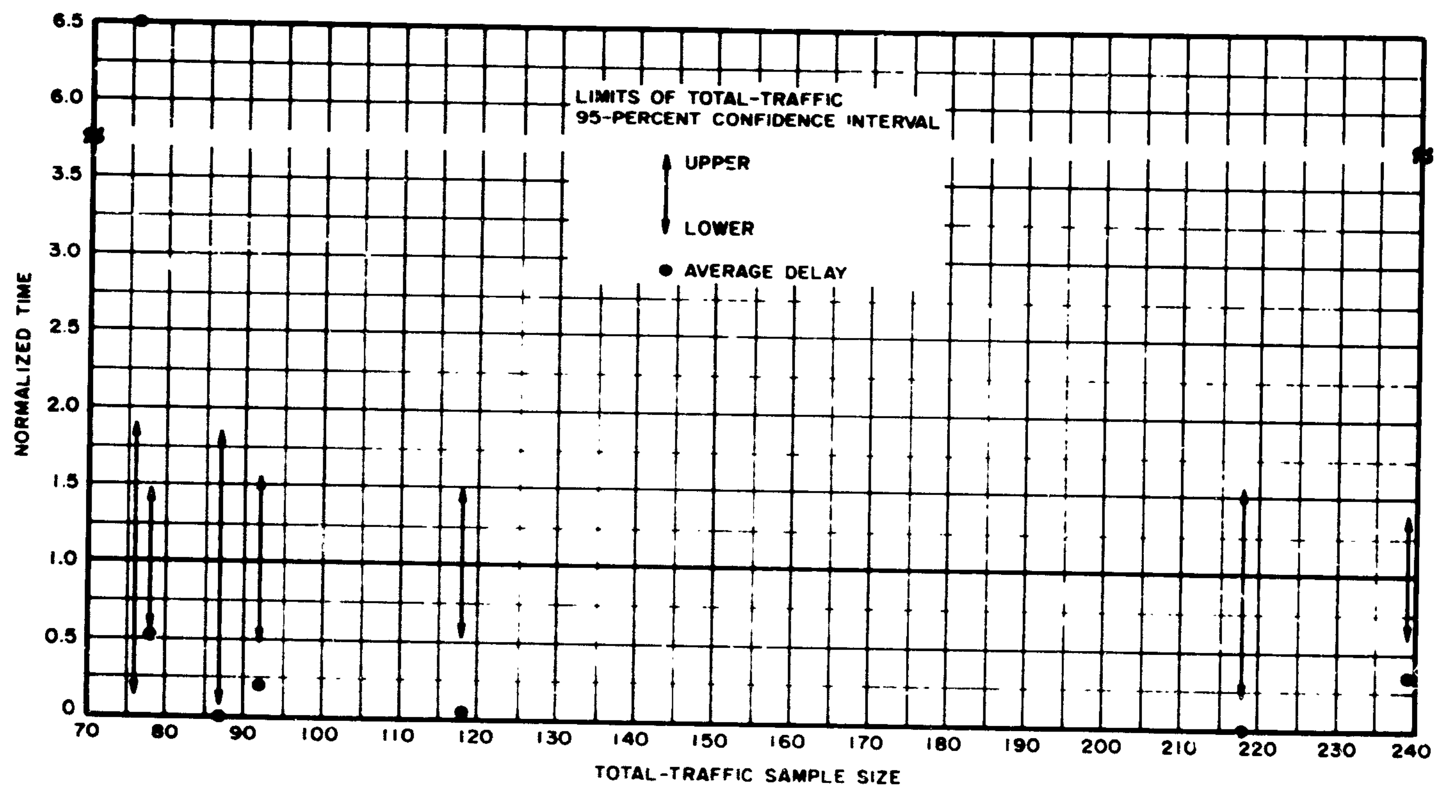

FIGURE 7. RELATIONSHIP OF GENERAL-AVIATION ARRIVAL DELAY TO 95-PERCENT CONFIDENCE INTERVAL OF TOTAL-TRAFFIC TRUE MEAN

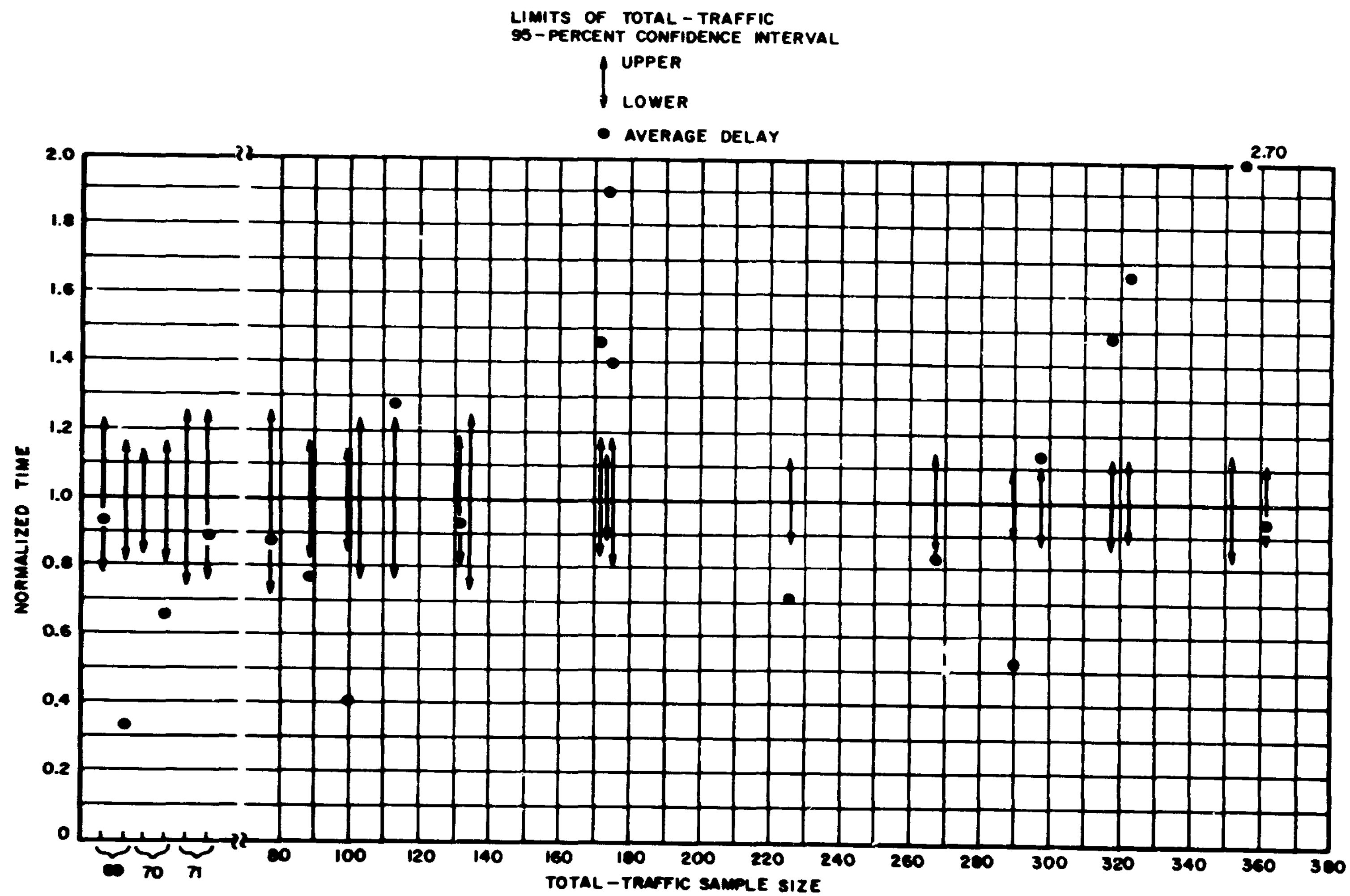

FIGURE 8. RELATIONSHIP OF MILITARY DEPARTURE DELAY TO 95-PERCENT CONFIDENCE INTERVAL OF TOTAL-TRAFFIC TRUE MEAN

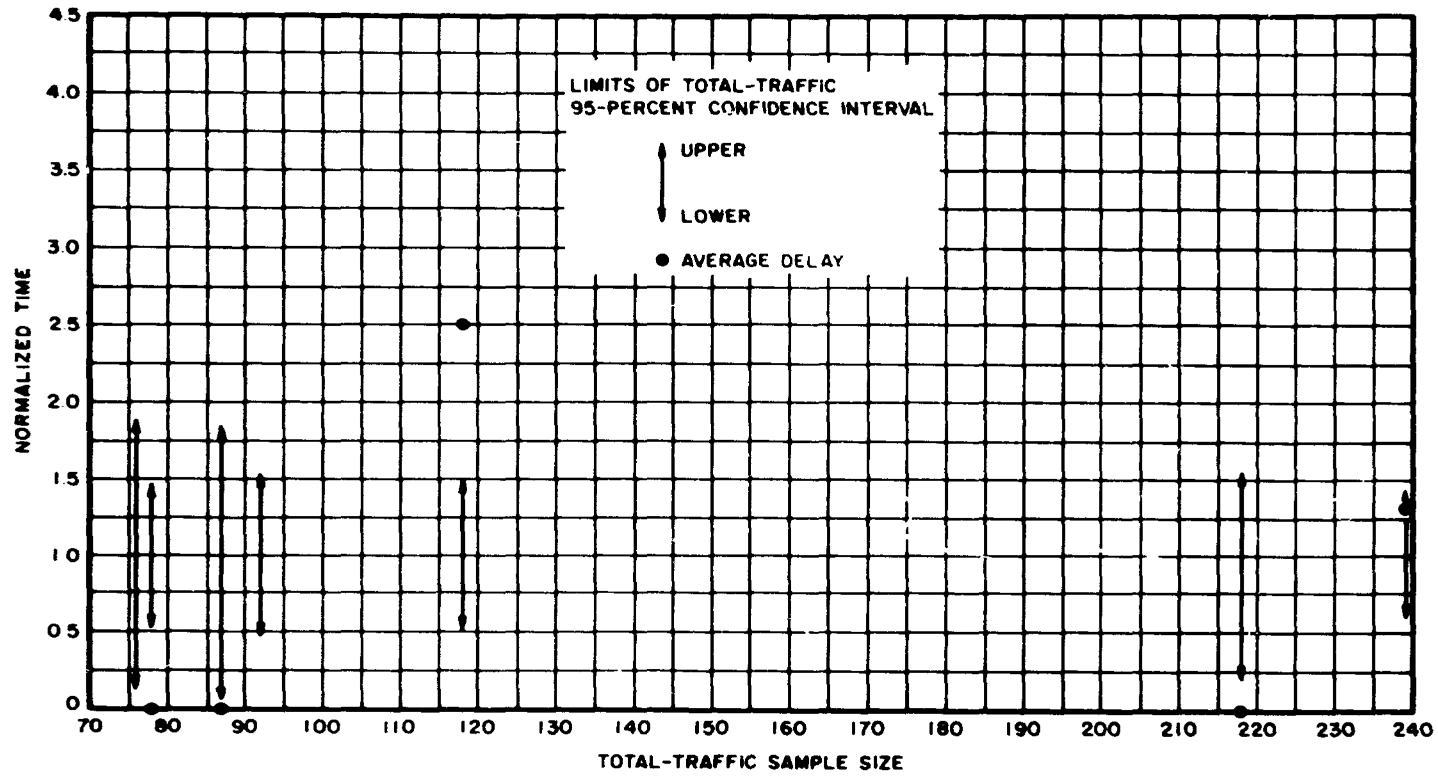

FIGURE 9. RELATIONSHIP OF MILITARY ARRIVAL DELAY TO 95-PERCENT CONFIDENCE INTERVAL OF TOTAL-TRAFFIC TRUE MEAN

departure delay (454 seconds). This large difference was due to the very low general-aviation average departure delay (137 seconds), which is explained later.

With regard to case 10, which is from LaGuardia Airport, air carriers represented only 38 percent of the total traffic. The case with the next lowest fraction of air-carrier traffic was case 23 with 59 percent. Here, the difference in average departure delays was only 3 seconds.

In Figure 3, all of the air-carrier average arrival delays were within the total-traffic confidence intervals with the maximum difference in average arrival days of 11 seconds in case 29. This is with the exception of case 30 where the delay difference was 47 seconds but the sample size (21) was too small to be considered.

From this discussion, we can conclude that where air carriers are a large fraction of the total traffic (say, greater than about 60 percent), air-carrier delay is a good representative of total-traffic delay with differences in average delays being about 1 minute or less for departures and about 10 seconds for arrivals.

Figure 4 shows the relationship of United Airlines average departure delay to the total-traffic confidence interval. In 12 out of 23 cases, the average departure delay fell outside of the total-traffic confidence interval. Average departure-delay differences ranged from 3 seconds (case 16) to 242 seconds (case 1).

It will also be noted that increasing the total-traffic sample size does not bring about more agreement between United Air-lines' average departure delay and total-traffic average departure delay. For each of the six cases of lowest total-traffic sample size (69, 70, and 71) and the six cases of highest total-traffic sample size (289, 297, 317, 322, 351, and 361), four cases fell outside of the confidence interval.

Of the 10 cases (cases 14 through 21 and 24 and 25) where United Airlines represented more than 20 percent (up to 33 percent) of the total traffic, four cases fell outside of the total-traffic confidence intervals. Differences in average departure delays for these cases ranged from 3 seconds (case 16) to 56 seconds (case 18). For case 18, this difference from the total-traffic average departure delay (178 seconds) is more than 30 percent.

In Figure 5, the United Airlines average arrival delay fell outside of the total-traffic confidence interval for six out of the seven cases. The differences of United Airlines' average arrival delay to the total-traffic average arrival delay ranged from 7 seconds (case 27) to 150 seconds (case 28). This is with the exception of case 30 whose difference was 356 seconds but whose total-traffic sample size (21) is considered inadequate.

From this discussion, we can conclude that United Airlines is not a good representative of total-traffic delay even when United Aircraft are 20 to 30 percent of the total traffic.

In Figure 6, the general-aviation average departure delay falls outside the total-traffic confidence interval in 16 out of the 24 cases. In 19 out of the 24 cases, the general-aviation average departure delay was less than the total-traffic average departure delay. The difference of the general-aviation departure mean from the total traffic departure mean range from 5 seconds (cases 3, 15, and 22) to 317 seconds (case 1). For the case with the highest percent of general-aviation aircraft studied (case 10, 62 percent), the average departure delay difference was 30 seconds or 17 percent of the total traffic-average departure delay. In Figure 7, all of the seven general-aviation average arrival delays were outside of the total-traffic confidence interval. We can therefore conclude that for the types of airports studied, general-aviation delays are not representative of total-traffic delays.

In Figure 8, we note that military average departure delay falls outside the total-traffic confidence interval 15 out of 20 times; in Figure 9, the military average arrival delay falls outside four out of five times. Therefore, military delay is not a good representative of total-traffic delay.

In Figure 10, the air-carrier 95-percent confidence interval is plotted for departure delay together with United Airlines average departure delay. The United Airlines average departure delay falls outside of the air-carrier confidence interval 13 out of the 23 times. The difference in United Airlines average departure delay from air-carrier average departure ranges from 1 second (case 16) to 139 seconds (38-percent difference, case 4). This is with the exception of case 6 (204 seconds) whose total-traffic sample size (15) was too small to be considered. Thus, United Airlines delay is not a reliable representative of air-carrier delay.

This statement cannot be generalized to include United Airlines at other airports or to any other airline. Its dependency would rely on several factors, which may include:

1. The percent that the airline represents of the total air carrier,
2. The kind of air carrier (short haul or long haul),
3. Operating procedures of the airline.

To form a composite picture of delay, all of the departure samples were combined, all of the arrival samples were combined, and then all of the arrival and departure samples were combined. The results are shown in Table III and on Figures 11 and 12. Figures 11 and 12 are not normalized and show, for each of the samples, the average delay and the 95-percent confidence interval of the true mean. Figure 11A shows that the total-traffic departure mean is 185 seconds and that the 95-percent confidence interval of the true departure mean is from 178 to 193 seconds. The air-carrier average departure delay is 198 seconds and is therefore outside of the total-traffic confidence interval; however, the difference is only 7 percent

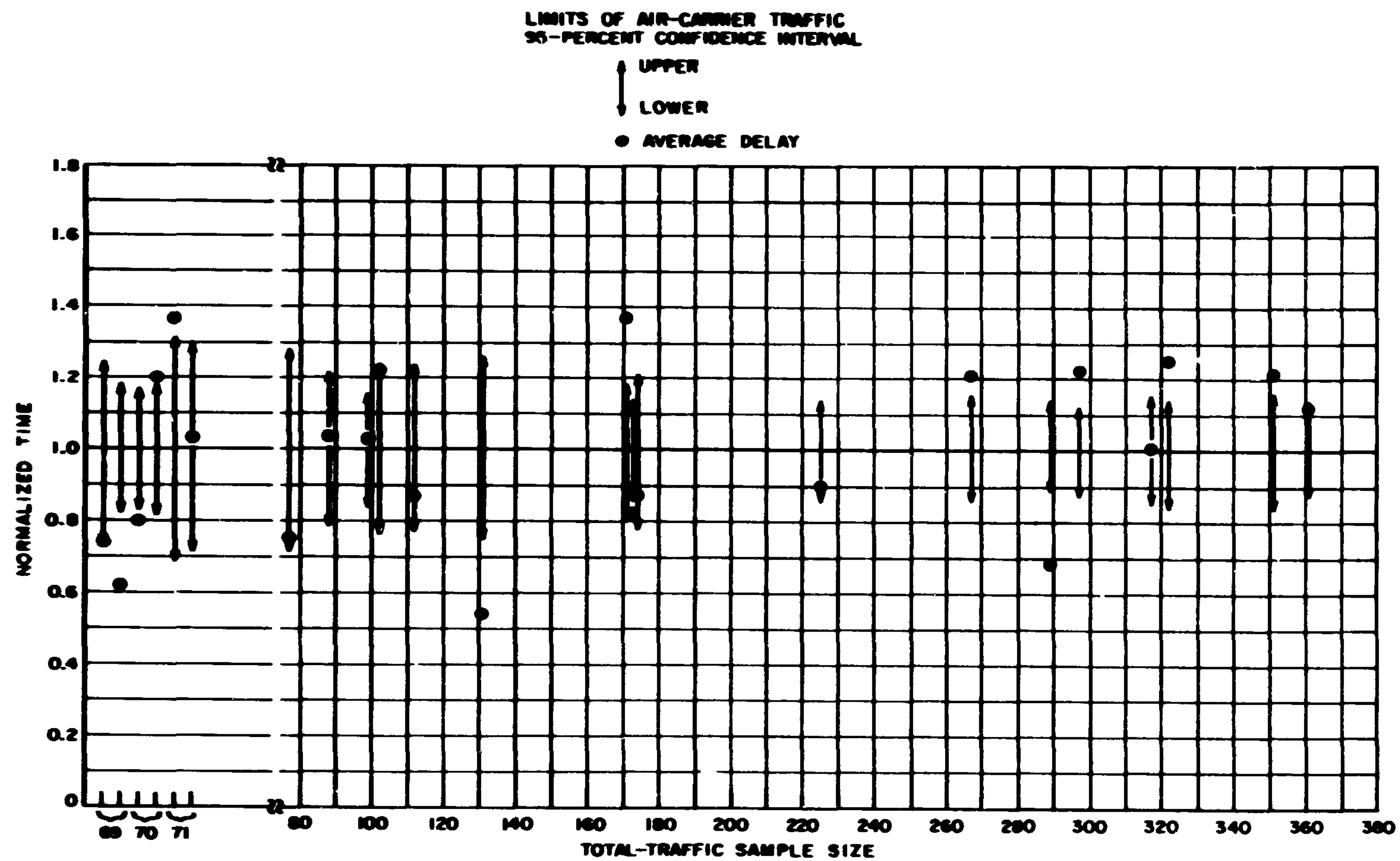

FIGURE 10. RELATIONSHIP OF UNITED AIRLINES DEPARTURE DELAY TO 95-PERCENT CONFIDENCE INTERVAL OF AIR-CARRIER TRUE MEAN

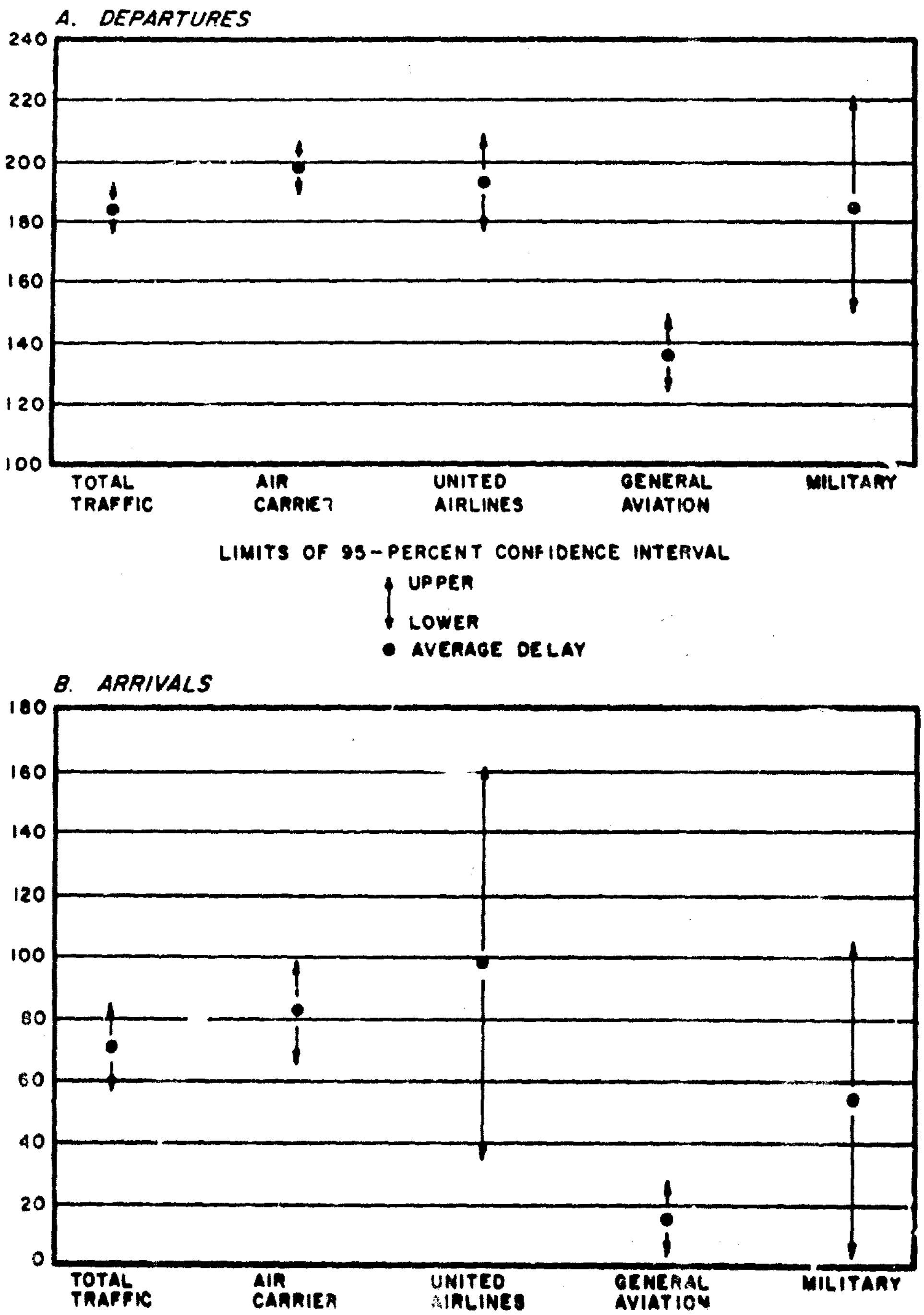

FIGURE 11. COMPOSITE OF DELAY

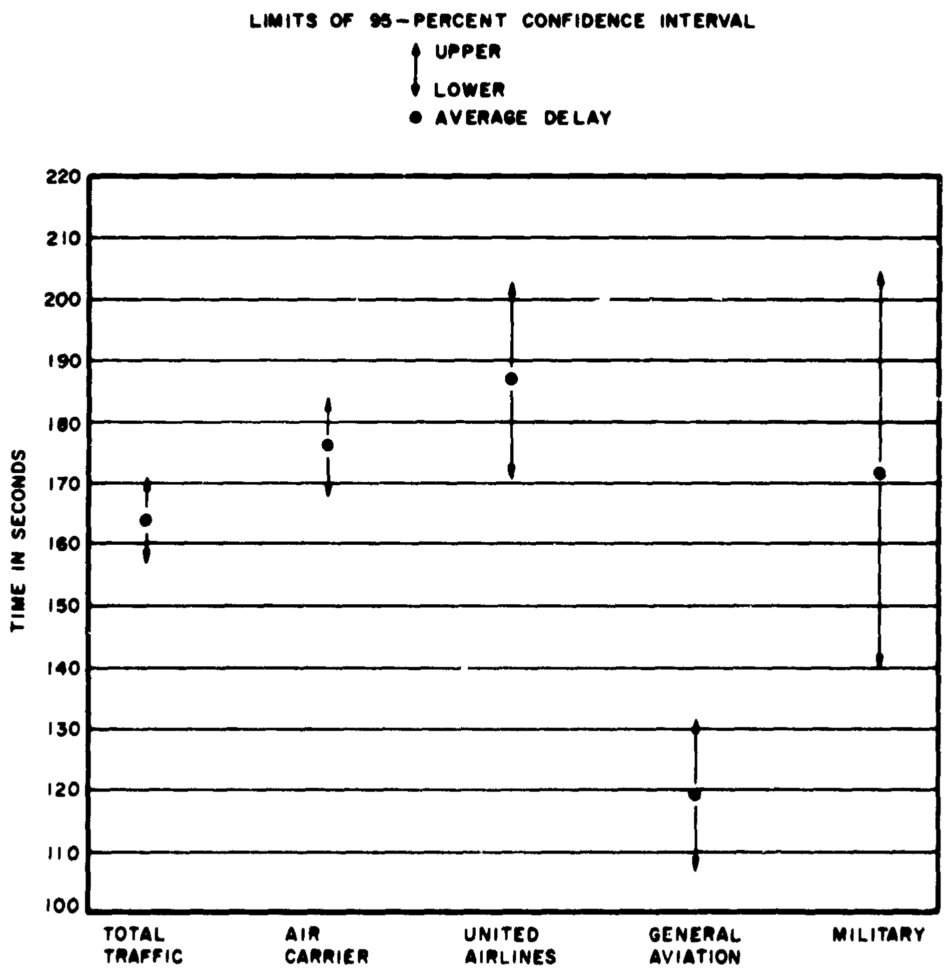

FIGURE 12. OVERALL COMPOSITE OF DELAY

from the total-traffic average departure delay. United Airlines average departure delay is 193 seconds, which places it on the edge of the total-traffic confidence interval. It should also be noted that United Airlines' average departure delay falls within the air-carrier confidence interval. The general-aviation average departure delay is 137 seconds, which is below the total-traffic confidence interval. In fact, the entire general-aviation confidence interval is below that of the total traffic. The military average departure delay is 185 seconds, which is the same as the total-traffic average departure delay.

In Figure 11B, only the air-carrier average arrival delay (83 seconds) lies within the total-traffic confidence interval (57 to 85 seconds). United Airlines' average arrival delay (98 seconds) lies within the air-carrier confidence interval (65 to 100 seconds). Again, the entire general-aviation confidence interval is below that of the total traffic.

For the overall composite of delay (Figure 12), none of the average delays were within the total-traffic confidence interval.

Figure 12 points out a tendency throughout the data--that is, air carrier and United Airlines' delays are higher than total-traffic delays and general-aviation delays are lower. From AIL experience and observations at airports, this tendency is explained by the fact that at the busier airports controllers and pilots take advantage of the short runway requirements and maneuverability of most general-aviation aircraft and use time-saving techniques for general-aviation traffic, which generally do not increase air-carrier delay but do reduce general-aviation delay. These techniques include the use of intersection takeoffs and of runways not suitable for or not being used by the larger aircraft.

IV. FINDINGS

1. At airports where air carriers are a large fraction of the total traffic, air-carrier delay can be used as representative of total-traffic delay.

2. At these airports, air-carrier average delay is larger than total-traffic average delay, and general-aviation average delay is smaller than total-traffic average delay.

3. In analyzing delay for several hours in a day, the delay experienced by a single airline is not representative of the total-traffic delay. However, when analyzing aircraft delay during a large number of days, the delay of a single airline may approach the total-traffic delay if that airline operates during the busy and slack periods of the day.

4. The delay to a single airline may not be representative of the delay to all air-carrier aircraft.

5. At the airports studied, military aircraft represented such a small sample that no reliable conclusions could be made.

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